BUREAU OF ECONOMIC GEOLOGY

Geological Circular 68-1

Glen Rose Cycles and Facies, Paluxy River Valley, Somervell County, Texas

By

J. STEWART NAGLE

The University of Texas at Austin

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J. Stewart Nagle[1/]

ABSTRACT

Paleoenvironmental analysis of the alternating beds of the basal Cretaceous Glen Rose Formation in Central Texas indicates a cyclical alternation of subtidal through supratidal facies. These facies were reconstructed through detailed analysis of lithology, biota (including macrofauna, microfauna, ichnofauna, and macroflora), detrital shell dispersal, and primary sedimentary structures. Facies succession indicates that each cycle represents a subtidal to supratidal depositional régimé transit; cycles are regressional, with the transgressional phase being poorly developed, if at all. This conclusion is in agreement with results of studies of the Holocene transgression, which reveal a regressional succession developed by progradation of shorelines. Some other formations show similar depositional régimé transit cycles; hence the Glen Rose model may be widely applicable.

Facies variations within and between cycles indicate (1) that there is no typical or ideal cycle, (2) that the cycles record successive sedimentation units within a marginal marine hypersaline lagoon or bay system, and (3) that depositional régimé transit cycles have limited correlation value. Facies in the seven cycles in the lower Glen Rose, Paluxy Valley, include subtidal to supratidal flat deposits, marsh, flood plain, shoal patch reef, bay, marsh island, and shifting sand lobe deposits; the only typical aspect of the cycles is their general subtidal to supratidal succession. Mixed terrestrial, marginal marine, and marine faunas and floras within these facies tracts indicate that the lower Glen Rose in this area is a lagoonal or bay depositional system. Paucity of terrigenous clastics, abundance of evaporites, presence of serpulid-patch reefs, and relatively low diversity of faunas with an abundance of thick-shelled ostracods indicate that at least the earlier phases of the lagoonal system were hypersaline. Areal stratigraphic correlation of these depositional régimé transit cycles is unwise because the cycles tend to proliferate downdip, and because units that could be used as key beds commonly are local in extent. These beds reflect similar depositional conditions which recur in homotaxial phases of different cycles; indeed potential key beds may change facies within a few miles, even

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[1/] Department of Geological Sciences and Bureau of Economic Geology, The University of Texas at Austin.

when bed thickness remains nearly constant. Correlation by matching cycles in sections less than a mile apart, however, is feasible.

Several particulars are useful in recognizing position in the cycle. Burrow fillings change upwards from lime-mud to sparry calcite or dolomite--a reflection of diagenetic rēgimē. Burrows with unlithified or partially indurated calcite mud and shells occur in subtidal sediments. Diagenetically modified burrows first appear in or above the zone of sorted and abraded shell, inferred to be the wave or beach zone. Diagenetic burrow modification is intrastratal; this plus the dense fabric with unaltered shells indicate early, soft sediment diagenesis. Paleoenvironmental evidence plus studies of the Recent support the idea that these diagenetic modifications are associated with exposure and solutional modification, dolomite by hypersalinity, sparry calcite by fresh water. Subtidal deposits contain articulated and unsorted shells, many in living position; nearshore wave zone or intertidal shells occur in beds of well-sorted and abraded detrital plates. Supratidal deposits abound in rollers or may contain abraded detrital plates in texturally inverted sediments. Supratidal marshes contain abundant remains of the plant Frenelopsis. Its tiny cells, thick epiderm, protected stomata, and poorly developed roots indicate it is a physiological xerophyte similar to Salicornia of present-day salt marshes.

INTRODUCTION

The 300 to 600 feet of basal Cretaceous rocks in North-central Texas are divided into three formations. Lowermost is a mixed terrigenous-clastic sequence, termed the Twin Mountains Formation (Fisher and Rodda, 1966). The middle unit, predominantly carbonate, is known as the Glen Rose Formation, and the upper arenaceous succession is called the Paluxy Formation. The arenites, especially the Paluxy Formation, thin or pinch out both to the south and downdip; they comprise less than 20 percent of the 700 plus feet of basal Cretaceous in Travis County. Conversely, the Glen Rose pinches out updip and to the north; in northern Wise County it is absent. In Somervell County, the area of study, all three formations are present. Each makes up about one-third of the basal Cretaceous sequence.

Throughout Central Texas the Glen Rose Formation consists of alternating beds of resistant and weak rocks that form distinctive stair-step topography. The resistant beds are either pure limestone, usually a spar-cemented calcarenite, or carbonate-cemented sandstone, whereas the weak beds are dolomite, dolomitic limestone, shaly limestone, mudstone, or uncemented sand. Topographically, individual units appear to extend for many miles without appreciable change in expression. But are these "weathering units" lithologically uniform throughout their lateral extent? And what is the significance of the alternations of hard and soft layers? What is the relationship of the precipitated carbonate

rocks to the terrigenous clastic rocks? A study of Glen Rose paleoenvironments has provided at least a partial answer to these questions, in addition to revealing many interesting aspects of Glen Rose facies relationships.

The area considered lies in the Paluxy River valley, 1 to 10 miles upstream from Glen Rose, Somervell County (fig. 1). Here, the Glen Rose contains three members: (1) a lower member of alternating terrigenous clastics and carbonates, (2) a middle, massive carbonate member, the Thorp Spring Member of Hill (1891), and (3) an upper member of alternating carbonates and terrigenous clastics. Seventeen sections have been measured in the lower member, in the interval between the famous dinosaur track bed and the base of the Thorp Spring Member; these sections are located on figure 1. In the field, rocks were classified according to Dunham's limestone (1962) classification. Specimens were slabbed in the laboratory and stained to determine calcite and dolomite composition according to Friedman's (1959) method. Carbonate rocks were named according to Folk's classifications (1959, 1962), sandstones according to McBride's (1963) classification, and mudstones according to a modification of Folk's fivefold micrite classification.

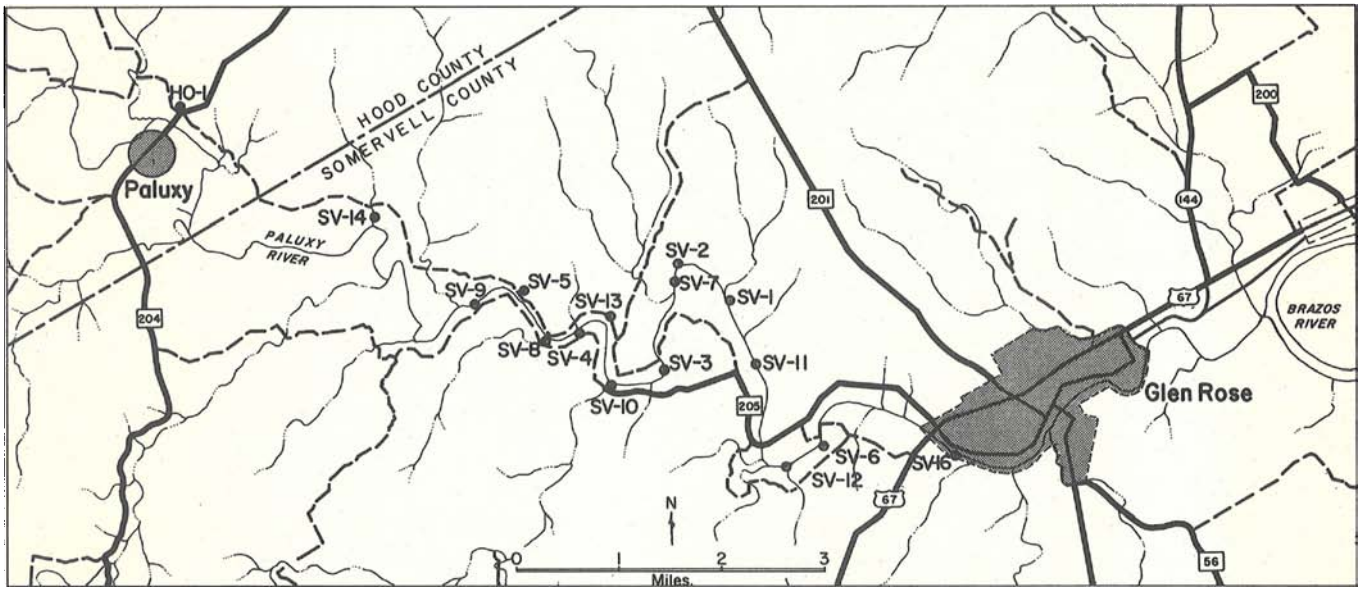

FIG. 1. Index map, showing locations of measured sections. Sections in Somervell County are indicated by SV, the one in Hood County by HO. (Base from Texas Highway Department County General Highway Maps 112 and 213.)

CYCLES IN VERTICAL PROFILE

Examination of vertical profiles yields some basic information about the nature of Glen Rose cycles. Figure 2 shows relationships in the vertical profile from SV-5, a representative and readily accessible section. The section runs from road level, up a small gully below the scenic overlook at the Cedar Brake Camp, to the base of the massive limestone that caps the hill (Thorp Spring Member).

Although the dinosaur track bed forms the bed of the Paluxy River here, the interval between it and the road is covered. The lowest bed on the profile (bed 1) is a gray, fossiliferous mudstone with a restricted molluscan-serpulid macrofauna, some of which are in living position, and an ostracod microfauna; the bed apparently represents restricted subtidal deposition. Overlying it is bed 2, which is a moderately resistant biosparite at the base, a root-mottled fine dolomite at the top, packed throughout with articulated, but detrital, shells of Corbula harveyi (Hill, 1893, p. 25) and other shell fragments. Shell sorting and packing at the base of the bed is excellent, indicating proximity to the zone of wave action; the top of the bed is not as well packed. However, this bed is nearly completely bioturbated, with galleried burrows below and roots above. There is no evidence for supratidally occurring large burrowers like fiddler crabs in the Lower Cretaceous; the galleried burrows were probably made by subtidal to intertidal organisms, probably mud shrimp. The roots are less than 2 inches long and probably belong to the physiological xerophytes whose remains abound in the overlying bed. Sorting, packing, and biotic distribution indicate this bed is shoaling intertidal. The overlying unit (bed 3) contains thinly interlaminated biosparite and dolomite; the only bioturbation it exhibits is root mottling, associated with common fragments of Frenelopsis, a plant interpreted as indicative of marsh conditions. The lack of burrows and the presence of these plants support the idea that this bed is supratidal. Bed 4 is clearly supratidal, being a gypsiferous irregularly mottled dolomitic shale with abundant Frenelopsis remains and scarce ostracods; characters of this unit closely resemble those of present-day marsh deposits. It should be noted that the succession of beds 1 through 4 is regressional, trending from restricted subtidal to a supratidal marsh. (Examination of nearby sections indicates that bed 1 immediately overlies a lignitic, laminar sand that probably represents a flood plain; there is no evidence of a transgressional succession of lithic units.) Bed 5 is a sparse biomicrite at the base; it is completely bioturbated, and some lime-filled, pencil-size burrows extend from this bed into the top of bed 4. As does bed 2, this unit becomes dolomitic upward and has a thin upper zone with roots. It is overlain by marsh deposits, nearly identical to those of bed 4. The transition from bioturbated micrite through rooted dolomite to plant-bearing shale suggests another regressional sequence, from shallow subtidal through subterrestrial marsh. Bed 6 contains an abundance of lime-filled burrows, extending downward from the base of bed 7, a muddy calcarenite which becomes

UNIT	BRIEF LITHIC DESCRIPTION	MAJOR FOSSILS	ENVIRONMENT
20	Basal unit, Thorp Spring Member. Calcarenite; buff, massive, thick bedded, with medium-coarse shell, angular, unsorted sparse biomicrite	Pelecypods - 10% Algae - 15% Gastropods - 5% Microfossils - 5% Bryozoa - 2%	Subtidal
19	Fossiliferous mudstone; olive, pencil-fissile, gypsiferous, plant and fine detrital shell-bearing shale	Microfossils - 8% Shell fragments - 2% Lignite - 2%	Marsh
18	Calcareous sandstone; medium brown, massively medium bedded, sorted, rounded, medium quartzarenite in micrite matrix. Lithophaga-bored and Crassostrea-encrusted cobbles at base of bed. Modiola clumps at top	Modiola - Tr. Microfossils - 12% Algae - 5% Roots - 2%	Mussel marsh Subtidal
17	Interbedded sand and shale; thin to medium bedded, tan, limonite-stained, fine to medium quartzarenite with partings of olive shale	Roots - Tr. Lignite - 3%	Floodplain
16	Fine sandstone; buff to tan, thick bedded, internal cut-and-fill, slump structures, dinosaur track-bearing, sorted, subangular quartzarenite	Lignite - Tr.	Fluviatile Channel
15	Fine calcarenite; reddish-brown, thinly rippled, sorted, miliolid biosparite with fine quartz-arenite at the top. Halite crystal casts. Ten cross-beds dip S. 60°E. to S. 30°W.	Miliolids - 30% Ostracods - 10% Corbula - 1%	Supratidal
15a	Interlaminated fine sand and shale; white to tan, fine, sorted, subangular quartzarenite and gray, lignitic clay	Roots - Tr. Lignite - 2%	Floodplain
14	Medium sand; drab, medium-bedded, sorted, subangular sublitharenite with internal laminae and cut-and-fill. Cross-beds dip east and southeast. Root mottled at top	Roots - Tr.	Fluviatile Channel
13	Calcilutite; limonite-stained tan, thick, massively bedded, medium shell, sorted, rounded, sparse dismicrite	Microfossils - 25% Shell fragments - 7% Algae - 2% Roots - Tr.	Supratidal
12	Fossiliferous calcilutite to calcarenite; limonite-stained or gray, burrowed, medium shell, angular sparse biomicrite, packed and sorted in middle of unit	Pelecypods - 3 to 35% Ostracods - 5% Algae - 2%	Intertidal Subtidal
11	Dolomitic calcarenite; brown, limonite-stained massive, medium shell, sorted, rounded, packed, burrowed, algal, fine dolomite	Ostracods - 5% Pelecypods - 15 to 40%	Intertidal
10	Sandy calcarenite; drab gray, medium irregularly bedded, crumbly, sorted, subrounded, packed, dolomitic (in burrows), quartz-arenitic biosparite. Sparse at bottom	Ostracods - 7% Pelecypods - 10 to 25%	Subtidal
9	As unit 4, but weathers blocky rather than into pencil fragments, with 20% sand	Roots - Tr. Shell fragments - Tr.	Marsh
8	Fossiliferous calcilutite; tan-gray, medium irregularly bedded, medium shell, angular-rounded, packed biomicrite. Biosparite at top	Algae - 15% Pelecypods - 10% Microfossils - 12% Oysters - Tr.	Intertidal Subtidal
7	As unit 4, but with 30% lime-filled burrows	Ostracods - 2%	Marsh
6	Muddy calcarenite; medium gray, massively bedded (conspicuously jointed), moderately sorted, packed, fossiliferous fine dolomite. Biomicrite at bottom	Ostracods - 5% Pelecypods - 10% Roots - 2%	Supratidal Intertidal
5	Plant-bearing mudstone; gray, pencil-fissile mudstone with Frenelopsis, sparse fine shell fragments and rare clusters of tiny gypsum crystals. Some fine dolomite	Ostracods - Tr. Frenelopsis - Tr.	Marsh
4	As unit 2, but thin, wavy bedded	Ostracods - 5% Frenelopsis - Tr.	Supratidal
3	Fossiliferous dolomite; tan, medium, massively bedded, sorted, packed, Corbula-ostracod fine dolomite. Biosparite below	Corbula - 10% Ostracods - 10%	Intertidal
2	Fossiliferous mudstone; gray, irregularly massive mudstone with a moderately diverse fauna, mostly detrital	Corbula - 10% Ostracods - 1% Pelecypods - 1% Algae, serpulids, gastropods - Tr.	Restricted Subtidal
1			

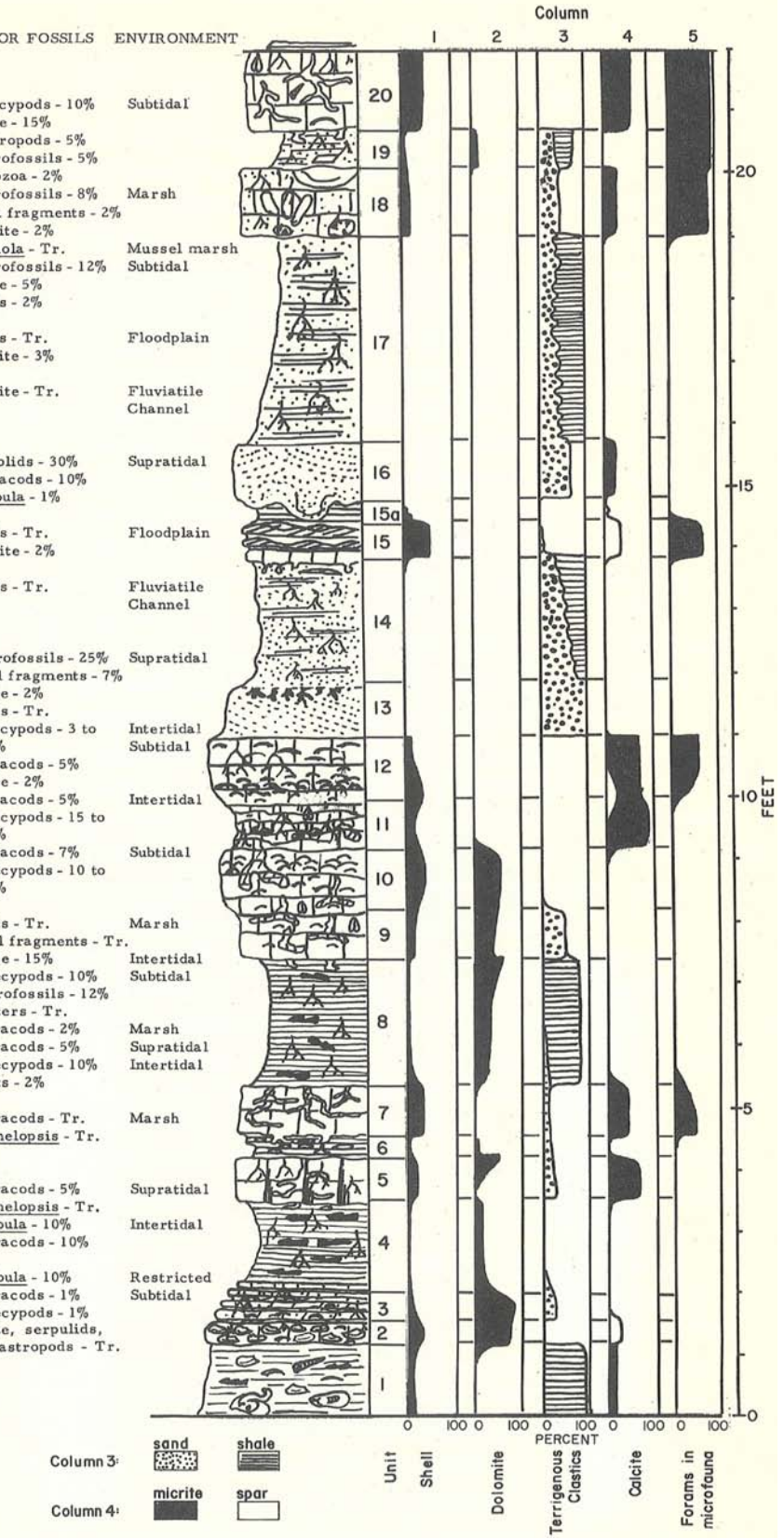

FIG. 2. Measured section, locality SV-5, Cedar Brake Camp, showing bed-for-bed changes in lithology and paleontology. All other sections were measured and studied in the same detail.

better washed upwards. Burrows toward the top of bed 7 are filled with dolomite instead of micrite. No roots were found at the top of this bed, but it is succeeded by a marsh deposit, similar lithologically to bed 4. Again, the succession from bioturbated shelly micrite (shallow subtidal) through washed biosparite (wave zone) to marsh shale is regressional. And so it goes up the section: beds 9-10, 11-14, 15-17, 18-19 represent four more regressional cycles. Details vary; the terrestrial phase of some of the upper cycles is represented by channeled flood-plain deposits; the subtidal phase ranges from algal calcarenite to mussel biomicrite. But the subtidal-supratidal regressional patterns hold, not only in the 16 other sections of the Glen Rose in the Paluxy Valley but also in 19 other sections from Johnson City to Twin Mountains. It is evident that the alternating beds of the Glen Rose represent cyclical repetition of regressions; but why regressions? Where is the transgressional phase? Studies of the Holocene may give an explanation. In diverse areas, from the Netherlands (Pannekoek, 1956) to the Gulf Coast chenier plain (Gould and McFarlan, 1959) and the Texas Coast (LeBlanc and Hodgson, 1959), geologists have found that Holocene accumulation has developed by progradation of shorelines. Thus, according to traditional concepts of the marine cycle, the Holocene sequence is primarily regressional; the transgressional phase is poorly developed, if at all. Repeated shoreline progradation may not be the only mechanism to produce the regressional repetition seen in the Glen Rose, but it can explain the pattern and is common today.

The cycles described are physically defined depositional units on a bed-for-bed scale, reflecting a depositional régimé transit which was probably terminated when local base level was attained. As such, it concurs with Wheeler's (1965) base-level transit cycle model, but on a small scale. The small-scale cycles should not be confused with the region-wide, formation-scale cycles of Lozo and Stricklin (1956) that are interpreted as physically defined time-stratigraphic units.

MEMBERS OF THE GLEN ROSE CYCLE

Although the Glen Rose depositional régimé transit cycles, as here studied, everywhere show an over-all subtidal-supratidal succession, there is no such thing as a typical cycle. Cycles vary considerably in detail. However, there are criteria for establishing stratigraphic position within the cycle, because some aspects of subtidal, intertidal, and supratidal sediments vary with depositional régimé, not lithology.

The base of the cycle is the first marine transgressional deposit and is recognized by the presence of subtidal to intertidal material immediately overlying supratidal to subterrestrial sediments. The most diagnostic feature is lime-filled burrows penetrating downwards into the supratidal sediments (fig. 2, beds 6, 8,

and 14, for example). These burrows are filled with unlithified to partially lithified micrite and in places are filled with shell debris representative of the fauna of the overlying subtidal to intertidal sediments. The commonest of these burrows are probably Callianassa burrows; morphologically they resemble the burrows of the extant mud shrimp Callianassa in that they are large, galleried, and walled. The only place Callianassa claws were found in the Glen Rose is in these burrows. These burrows occur below sediments with supratidal wind-tidal flat structures or marsh deposits; they occur within or below the zone of greatest shell sorting--the beach zone. According to Hoyt and Weimer (1963, p. 530), the upper limit of Callianassa today is at mean sea level; from the occurrence of Callianassa and associated burrows in the Glen Rose, it appears that the same distributional pattern held in the Cretaceous; the burrows were intertidal to subtidal. The succession of fillings in Callianassa-type burrows is everywhere from lime-filled upward to sparry calcite-filled or dolomite-filled. It is known from studies of the Recent that early diagenetic processes responsible for sparry calcite cementation or dolomitization take place primarily above mean sea level, sparry calcite by fresh-water diagenesis (Friedman, 1964, pp. 810-811; Land, 1966, p. 2), dolomite by hypersaline diagenesis (Deffeyes et al., 1965, p. 71; Illing et al., 1965, p. 89). No early diagenetic effects are seen in rocks that remained below sea level and in contact with water of approximately marine water proportions (Friedman, 1964, p. 811). (Layered dolomite in the lower Glen Rose of the Paluxy Valley follows bedding, is dense rather than porous, does not replace shells, and associated with structures indicative of supratidal environments; it is very probably prelithification supratidal dolomite and not the reflux dolomite of Adams and Rhodes (1960) which cuts across bedding and environments.) While the lime mud in the subtidal Cretaceous burrows is stabilized to calcite, it tends to be weakly lithified, showing no evidence of early diagenetic lithification. The association of lime-filled burrows and diverse subtidal faunas in living position suggests that the rocks were not exposed to early diagenesis. Dolomite and sparry calcite-filled burrows occur higher in the cycle, within the zone of greatest shell sorting and rounding, and are commonly packed with abraded shell in the diagenetically modified matrix. Textural evidence, plus succession in the cycle, supports the idea that these burrows were formed intertidally; studies of the Recent demonstrate that diagenetic alteration of intertidal sediments is common (Illing et al., 1965; Kaye, 1959; numerous others). Hence, the altered burrows probably underwent intertidal exposure diagenesis; unaltered burrows probably did not but remained subtidal. The lime-filled burrows penetrating into the supratidal sediments from the basal biomicrites of the next overlying transgressional phase originated subtidally and were never subjected to diagenesis associated with exposure.

Shape and size sorting of shells is useful in interpreting position within the cycle. Detrital shell forms have previously been classified as plates, cones, and rollers (Nagle, 1967, p. 1125). Plateform shells (pelecypods, for example) are difficult to move, especially where convex upward. During transport by

physical processes, they skid along the bottom and are commonly trapped by bottom irregularities. Conical shells move by rolling downcurrent and sideways on the long axis and are moderately difficult for physical processes to move. Spherical or smooth fusiform shells--rollers--roll very easily on the cylindrical axis and are commonly transported long distances from their site of origin. In experiments with mixed assemblages of shells, it has been found that rollers are the first to be sorted out and are transported to quieter areas. They are commonly concentrated onshore, on supratidal deposits, or offshore, past the zone of wave action. Cones may or may not be moved, but these forms are commonly trapped in subtidal macro-epibenthic plant beds. Plates tend to be left behind as a lag residue in higher energy areas.

Within the cycle, the subtidal phase shows the greatest faunal diversity, in terms of number of species in living position. Some of the biota is in living position, especially shallow burrowing pelecypods such as Arctica and Meretrix, as well as epifaunal forms. This contrasts strongly with the primarily detrital or deep-burrowing fauna of the other phases. Texturally, subtidal sediments tend to be immature in the sense of the Folk (1962) classification. These immature sediments underlie more mature--better packed, sorted, and abraded--sediments from shallower, more agitated zones. Detrital shells are unsorted; there is range of shapes and sizes of plates, cones, and rollers. Subtidal shells commonly show angular fracture, rather than rounding. The larger shells tend to show wave orientation (Nagle, 1967), although smaller shells are irregularly oriented because of bioturbation. Bioturbation and burrow mottling are normally complete, undoubtedly because intensity of biogenic reworking by the abundant biota was greater than intensity of physical processes (Moore and Scruton, 1957, p. 2745). These sediments are normally unlithified. All the carbonate is in the stable form of calcite, but the sparry cement of fresh-water diagenesis and the dolomite and evaporites of hypersaline diagenesis are absent.

The intertidal phase is herein defined to include tidal flat and beach deposits. In the Glen Rose, this phase overlies sediments with the characteristics described above. Evidence for intense action by physical processes and partial exposure is abundant in this zone. Intertidal sediments are always the coarsest and best sorted of the cycle; they are commonly texturally mature to supermature and contain an abundance of rounded fragments of plateform shells. Such shells are convex upward or concentrated in shell hash. Orientation patterns tend to be bimodal, beach-type alignments (Nagle, 1967, p. 1132). The only living fauna is represented by deep-burrowing pelecypods; all the other shells are detrital. Dolomite-filled burrows prevail in this zone; the rest of the rock is commonly cemented by sparry calcite or dolomite. Bioturbation in muddy beds is extensive; in coarser sediments, one finds low-angle inclined beds of beach deposits (van Straaten, 1959, p. 204) or irregular laminae similar to those described by Scott (1964, p. 49). Stromatolites occur intertidally in Baffin Bay, Texas (Dalrymple, 1964, p. 2) and in the Persian Gulf (Kendall, 1966, pp. 132-135) and are considered as intertidal in the Glen Rose.

Supratidal sediments are of two types: marsh shales, similar to those described by van Straaten (1959, p. 210) and Scruton (1960, pp. 88-90) with abundant root mottling, organic matter, and pencil-fissility, or mixed-arenites similar to those described by Rusnak (1960, pp. 180-183) and Scott (1964, pp. 49-53). Where root mottling is absent, bioturbation is minor. Faunal diversity is very low; nearly all shells are detrital fragments, primarily rollers. Texturally, shells show inversions, such as rounded large plates in a mud matrix, mixtures of angular plates and abraded rollers, and many other unusual admixtures. Diagenetic alteration of carbonates is universal, usually in the form of hypersaline alterations that show associations of dolomite, salt crystal casts, celestite, and gypsum. Similar associations are found today in supratidal sediments of the Persian Gulf (Illing et al., 1965, p. 89), the West Indies (Deffeyes et al., 1965, p. 85) and Laguna Madre (Rusnak, 1960, p. 194). Plants and plant fragments are nearly ubiquitous in this phase. Of these, Frenelopsis, the commonest form, shows the thick epiderm, tiny cells, and fine, well-protected stomata of xerophytes. It is always associated with systems of tiny roots, rarely over 2 inches long. Such reduced roots are characteristic of physiological xerophytes, plants subjected to osmotic desiccation such as is found in salt marshes. Morphologically, Frenelopsis closely resembles the present-day salt marsh plant Salicornia. If this root association is correct, Frenelopsis is the Cretaceous analog of Salicornia.

Flood-plain wedges intrude the marine cycle pattern. These overlie the supratidal phase, thicken updip, and are comprised of finely interlaminated yellowish sand and gray clay with abundant lignite. Rarely, one finds zones mottled by large roots. Channel sands appear at many places in this facies. Evaporites of the supratidal phase are absent, as are marine shells. Diagenetic alteration of carbonates and cementation of sediments is almost non-existent.

The above criteria distinguish the best-developed aspects of the cycle; demarcation between different phases is not always very sharp. The dividing line between the top of one cycle and the base of the next can usually be discerned by changes in biota, sedimentary structures, mineralogy, and burrow fillings, but units within a cycle are commonly transitional and may have no sharp boundaries. However, the general subtidal-supratidal succession holds up consistently.

FACIES RELATIONS WITHIN INDIVIDUAL CYCLES

Corbula-bed cycle (beds 1 through 4 of fig. 2). --The Corbula-bed cycle is the first cycle above the dinosaur track bed that in many places forms the bed of the Paluxy River. It is the lowest complete cycle seen in outcrop and for practical purposes is the first cycle in the lower Glen Rose. There are two distinctive units in this cycle. The middle unit has been equated with the Corbula bed in Central Texas, supposedly a zonal marker separating the lower

and upper Glen Rose (Whitney, 1952, p. 65). In the Paluxy Valley, it is a thin, irregularly bedded, moderately resistant calcarenite packstone to grainstone bearing exceedingly abundant articulated detrital Corbula harveyi. (There are at least three other Corbula beds in the lower Glen Rose, but this is the only one to contain articulated detrital Corbula in a shell hash.) The lower unit of this cycle is a distinctive "steinkern marl," a shaly biomicrite wackestone with abundant limestone nodules and pelecypod and gastropod steinkerns that are sparsely encrusted with large serpulid worm tubes. Lateral variations in this cycle are largely in the direction of dip (fig. 3).

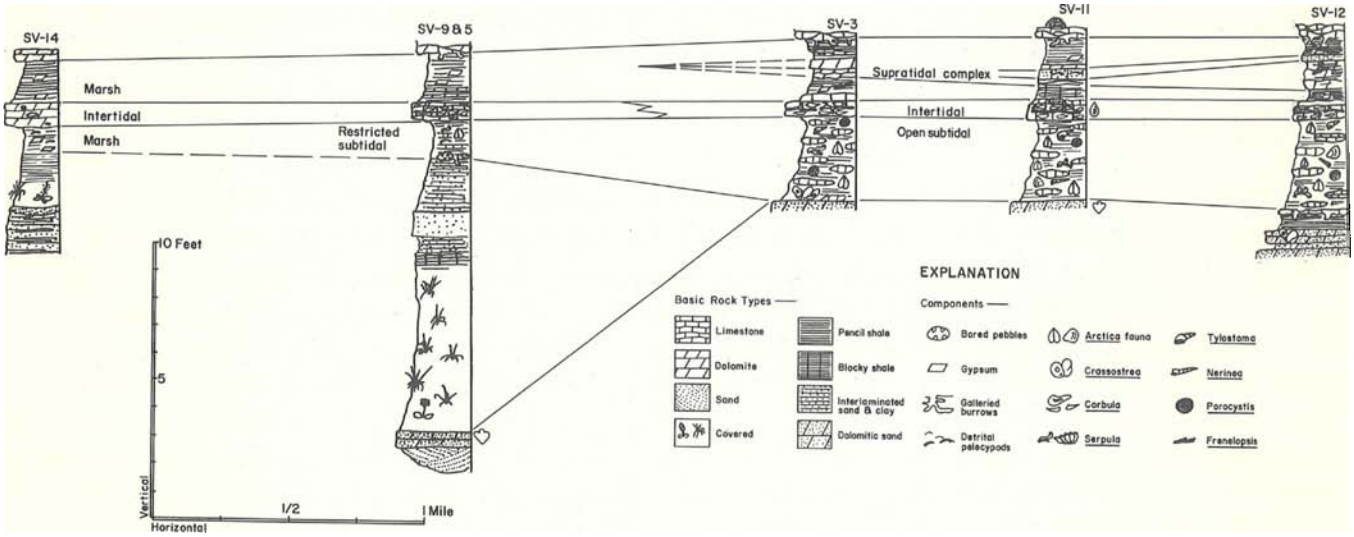

FIG. 3. Facies changes within the Corbula-bed cycle. In outcrop, this cycle is characterized by an intertidal Corbula accumulation which can be traced for several miles but which is not regionally persistent.

This cycle ranges from 3.5 to 7 feet thick, with the subtidal phase being 1.5 feet thick updip, 3.5 feet thick downdip, the intertidal Corbula bed remaining a nearly constant 0.6 to 0.8 feet thick throughout, and the supratidal phase increasing in thickness from 1.5 feet to 2.3 feet downdip. The cycle begins immediately above the dinosaur track bed southeast of SV-3; northwest of SV-5 its base is marked by a zone of lime-filled burrows and bored cobbles about 12 feet above the dinosaur track bed. The cycle is not exposed between SV-3 and SV-5; intermediate relationships cannot be seen.

The lower steinkern marl has a rather diverse fauna. In this unit, one finds up to 18 taxa of pelecypods, gastropods, and an abundance of serpulids, many in living position. Taxonomy is similar to that of the next cycle. The abundance of serpulids and the absence of Foraminifera suggest abnormal salinities. Faunal diversity falls off to the northwest; there are 18 genera at SV-12 and only two at SV-14, where all of the shells are detrital (fig. 3). The lower unit is shalier to the northwest and at SV-14 is a laminated, gypsiferous, plant-bearing shale instead of a steinkern marl. The cycle is incomplete at SV-14 but can be inferred by tracing it downdip to SV-5.

The Corbula bed also changes updip, from a burrowed packstone biosparite at SV-12, to a packed calcarenite with a fine dolomite matrix at SV-3, to a sparsely fossiliferous fine dolomite at SV-14. Abundant ostracods take the place of Corbula at both the top of the bed and updip. Only one genus, Eocytheropteron, is prevalent, however. Southeast of SV-3 there are conspicuous dolomite-filled galleried burrows; these disappear by SV-14. Southeast of SV-2, there are scattered serpulid reefs on top of this bed.

Great changes take place in the upper unit, which is a plant-bearing shale to the northwest (SV-5, SV-14). Several additional units appear downdip. Gypsiferous shales and dolomites come in by SV-3; by SV-12, one finds a succession of burrowed biomicrite, supermature sand with coarse plateform shells, and ostracod-bearing dolomite, all within the shales. It is apparent that a new cycle is developing within this unit.

The lower unit represents an abnormal salinity bay, with its relatively diverse, but restricted, fauna. Scattered oysters at the base suggest lowered salinity similar to conditions in Laguna Madre as interpreted by Rusnak (1960, p. 193). In the upper part of the unit, however, the Corbula and thick-shelled ostracod (Eocytheropteron) association is reminiscent of the hypersaline association of Behrens (1965, pp. 88-89), although miliolids as described by Behrens are not present in the Paluxy Valley sections. The writer agrees with his interpretation; the fauna indicates a hypersaline association, and his argument can be supported with two more criteria: (1) Serpulid reefs are known from hypersaline Baffin Bay and Laguna Madre (Andrews, 1964, p. 103), as well as the Corbula-bed cycle of the Glen Rose. (2) Abundant evaporites (gypsum) are found in the upper part of the Corbula bed and the overlying shales. The Corbula bed was probably shallow subtidal to intertidal, as shown by exceedingly good sorting and packing. At SV-1 and downdip, the bed was probably subtidal, a bay margin type of deposit that was completely bioturbated and encrusted with Serpula reefs. From SV-3 updip, the Corbula bed becomes poorer packed and better laminated, grading from intertidal to supratidal. The upper unit represents a flood plain at SV-14; it grades into a marsh by SV-5 and is invaded by a new cycle by SV-1.

The facies changes within the Corbula bed represent the most important general consideration to be gained from the study of this cycle. Like many other beds in the Glen Rose, the Corbula bed does not vary much in thickness but changes facies drastically within a few miles.

Serpulid-reef cycle (beds 5 and 6 of fig. 2). --This is the second cycle above the dinosaur track bed; it immediately overlies the Corbula-bed cycle. Recognition of the basal unit, a poorly washed biosparite with serpulid-patch reefs that are up to 3 feet in diameter, serves to identify the cycle; where there are no serpulids, the cycle can be recognized only on position in the section. Total thickness increases downdip, from 1.2 feet at SV-14 to 3.1 feet at SV-11, with the subtidal-intertidal phase being 0.6 and 2.1 feet thick and the supratidal phase being 0.6 and 1.0 feet thick at SV-11 and SV-14, respectively.

The most interesting aspects of this cycle appear in the lower unit, presented here in map reconstruction (fig. 4). Figure 4-A shows thickness and lithic changes; the northwest-trending embayment of biomicrites with the belt of poorly washed biosparites northeast of it should be noted. These packstones correspond to the areas of maximum serpulid-reef development, as seen on figure 4-B. Both faunal diversity, in terms of macrofaunal genera, and the character of the fauna change southwest and updip from this trend. At SV-11, within the serpulid-reef trend, a diverse fauna has been recognized, including: epifaunal suspension feeders, two species of Serpula, Trigonia, and Arca; infaunal suspension feeders Liopistha, "Arctica," Meretrix, Corbis, and Homomya, plus the snails Tylostoma and Nerinia. Much of this fauna is in living position. Green algal plates and ostracods abound in this section. By SV-10, the serpulids have dropped out, and the only form in living position is the deep-burrowing suspension feeder Homomya, in a sparse biomicrite matrix. By SV-5, the shells are detrital, packed in a biomicrite matrix which becomes dolomitic with roots at the top of the bed. At SV-14, most of the detrital shells are rollers and very small plate fragments in a matrix of fine-grained dolomite with sparse gypsum.

It appears that the lower bed of the serpulid-reef cycle represents a hypersaline bay, similar in some aspects to Baffin Bay on the Texas Coast (fig. 4-C). The fauna, although diverse, is not nearly as diverse as in many parts of the Glen Rose, the Thorp Spring Member, for example. A microfauna comprised exclusively of ostracods suggests abnormal salinity; the presence of serpulid reefs is similar to that in hypersaline Baffin Bay. Sediment mineralogy helps support the concept of hypersalinity; Recent dolomites are being formed in hypersaline lagoons (Alderman and Skinner, 1957, p. 567), or evaporitic supratidal flats (Illing et al., 1965, pp. 89, 97-101; Deffeyes et al., 1965, p. 74), and associations of dolomite and gypsum in the Glen Rose suggest hypersalinity in the Cretaceous. The serpulid-reef tract, associated with biosparites, appears to be similar to that of Baffin Bay, which has serpulid reefs on shoals (Andrews, 1964), the packstone shoals, of course, bearing greater wave and current activity than the micrites behind them. The thin, but mile-wide zone of micrites that contains an intermediate diversity fauna with only deep burrowers in living position is taken to indicate a low-tide-range tidal flat, if it holds that the deep burrowers were the only forms able to withstand the periodic desiccation of tidal-flat conditions. Winnowed and sorted plateform shells overlain by rooted dolomites suggest a high, wave-swept tidal flat to marsh at SV-5. These flats were near the source of shell; waves and currents were strong enough to winnow out rollers and wash them farther up on the flats, to places such as located by SV-14, a dolomitic, gypsiferous marsh.

Both this cycle and the Corbula-bed cycle thicken downdip, in contrast with the upper cycles which thicken updip, because of interbedded sand wedges.

Marsh-land cycles (beds 7 through 10, fig. 2). -- The next two cycles are in the middle of the Lower Glen Rose and are best recognized by position in the section and by a 2- to 3-foot thick succession of uncemented calcareous mudstone

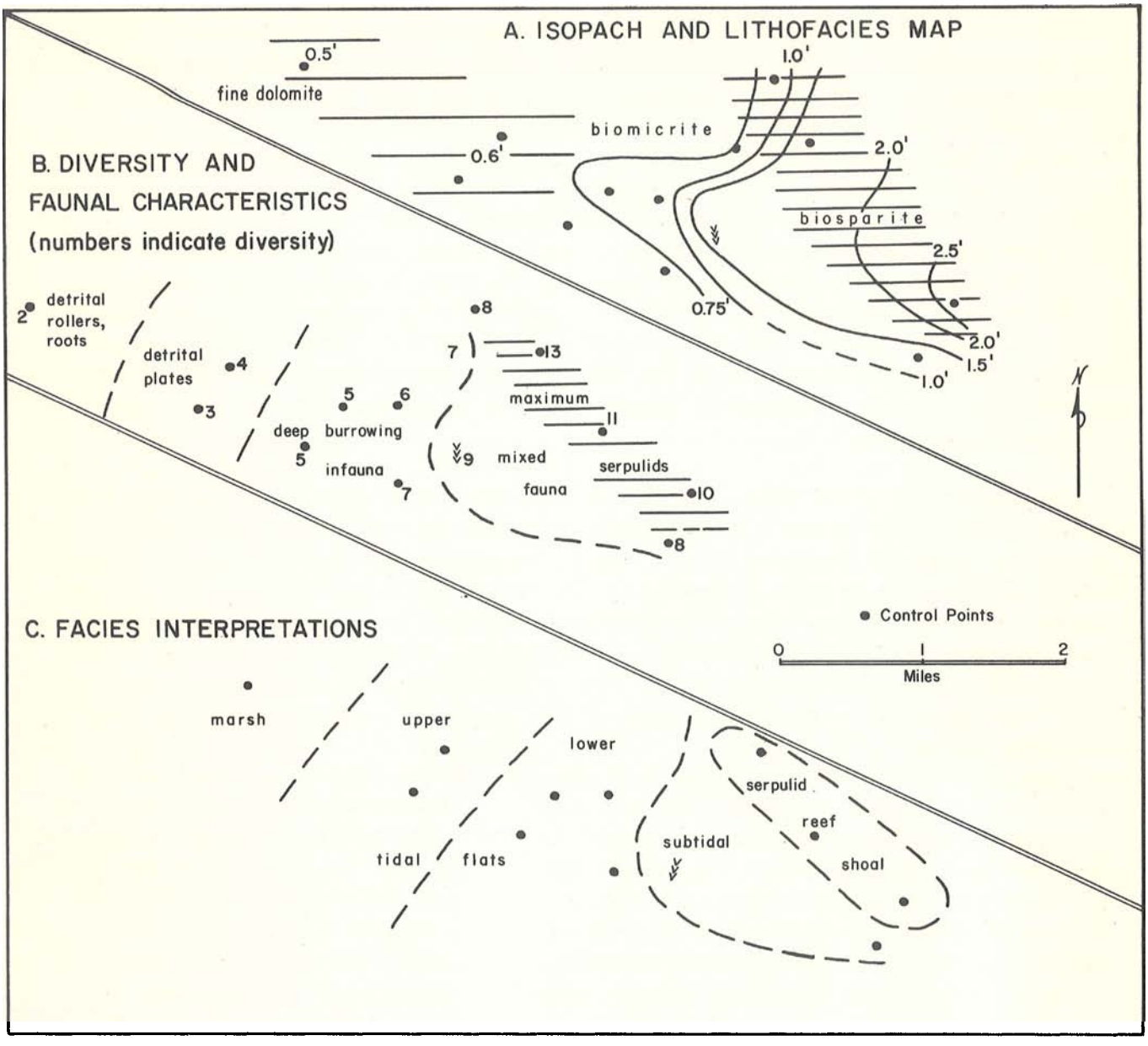

FIG. 4. Facies changes within the serpulid-reef cycle. This cycle is characterized by an abundance of serpulid reefs in some sections. (A) shows total rock thickness in this cycle as well as major lithology. (B) shows faunal diversity in genera per locality as well as trends in both detrital and in situ fauna. From these parameters, facies interpretations were prepared, as represented in (C).

with abundant plant fragments. The lowest bed of these two cycles is the first bioturbated bed above the serpulid-reef cycle; the highest unit is the uppermost bed below either a prominent, massive biosparite that weathers into large flags about 8 inches thick, or the lowest U-shaped burrow bed. Because individual beds are thin and facies relations within these cycles are complex, interrelations are best seen in a generalized fence diagram (fig. 5). Thickness of these cycles ranges from 3.8 to 5.1 feet, with maximum thickness at SV-3, where the supratidal phase is thickest.

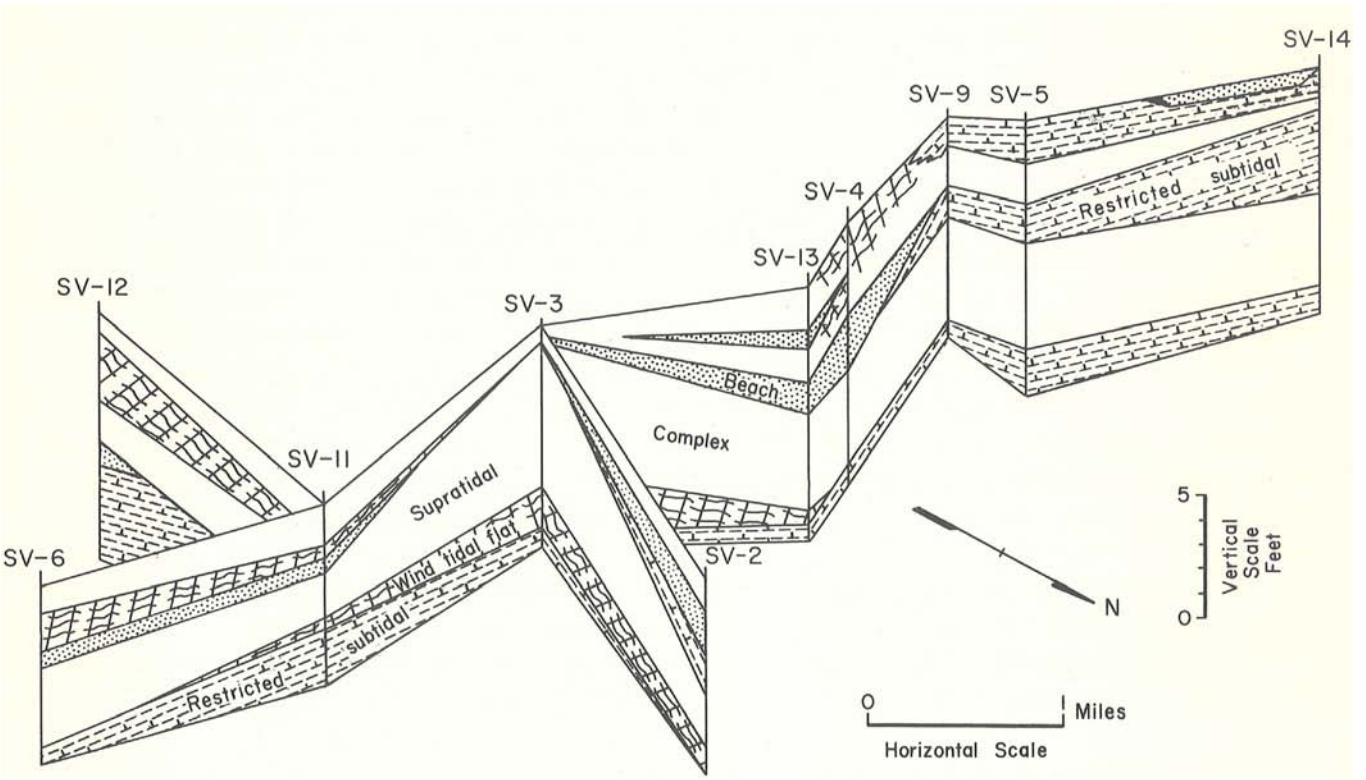

FIG. 5. Facies reconstruction of marsh-land cycles, so named because the predominant lithology is a shaly marl with abundant plant remains and root traces, presumably a marsh deposit. Facies changes are detailed in the text.

The lowest unit everywhere is a wispy, galleried-burrow biomicrite with a restricted fauna. This fauna suggests unusual salinity, probably hypersalinity for the reasons previously discussed (p. 12). This bed is thickest and muddiest at SV-12 and SV-5 and is thinner, winnowed, and packed in a belt from SV-6, northwestward through SV-2, and surrounding SV-3. The thick muddy portion is undoubtedly an offshore subtidal facies; the thinner, better sorted part of the bed represents an onshore subtidal facies, probably a bay or lagoon. Overlying the subtidal facies at SV-12, the Barker Branch section, is a sorted, laminated medium sand with low-angle cross-beds and ripples dipping S. 45° E.; the sand body itself trends ESE-WNW. Detrital Corbula abound in some beds; they show bimodal orientation perpendicular to the trend of the ripples. The lentiform shape, coarse grain size, low-angle bedding, and shell orientation support the idea that this was a beach. Further evidence for this comes from matching sections within 100 yards of each other near the mouth of Barker Branch. To the southeast of the beach, but at the same level, is a washed biosparite that is completely bioturbated, probably a shallow subtidal deposit. A laminar, plant-bearing shale falls in this interval to the northwest; it is probably a marsh. Southeastward-dipping rippled beds in the beach concur with this paleoslope picture. Within the marsh deposits are 1- to 6-inch-thick, calcareous, laminated clays with excellently preserved, but broken, plants, primarily Frenelopsis, Brachyphyllum, Pagiphyllum, Abietites, and Williamsonia. These unbioturbated clays with articulated plants are probably storm-deposited clay drapes; the plants have the appearance of beach wrack that may have washed in during the storm. Beds with the composition and structure of the clay drapes reach a maximum thickness of 2.7 feet at SV-3; these pinch out and are replaced by typical marsh shales by SV-4. In turn, the marsh complex is replaced to the northwest by thinly interlaminated lignitic sands and clays of a flood-plain complex. Underlying the marsh phase to the north is a sparsely fossiliferous dolomite containing sorted detrital shells, algal-mat laminae, and abundant celestite; this facies resembles a hypersaline supratidal flat. The whole cycle appears to represent a southward-opening hypersaline bay, overlain by a beach to the southeast that was contemporaneous with a marsh and hypersaline supratidal flats to the northwest. Clay drapes from storms covered the southeastern part of the marsh during this phase.

Whereas marsh deposition was nearly continuous during these cycles at SV-3, subtidal and intertidal deposition took place in surrounding areas. The subtidal complex of the next cycle entered the area from the north and west and forms a wedge that nearly penetrates to SV-3. The subtidal phase of this transgression appears in a belt from SV-2 and SV-4 westward and is represented by a completely bioturbated, poorly washed biosparite, again with a restricted fauna. A well-sorted, rounded, poorly bedded Corbula biosparite falls in this interval from SV-6, in an arc northwestward around SV-3, and overlaps the subtidal phase northward and westward. Corbula oriented parallel to the ripples in characteristic wave orientation indicate waves from the west. The coarsest and best-sorted shell occurs to the north and west of SV-3; fine-grained supratidal flat deposits

occupy this interval to the southeast. The grain-size pattern indicates a source of wave energy from the west, and probably north. This wave pattern roughly agrees with Young's (1959, p. 163) interpretation of southwesterly waves during deposition of the Edwards. The whole cycle appears to represent a shallowing bay with adjoining beach surrounding the topographic high at SV-3. A third transgression is locally represented in SV-13 and westward, as an algal-rich bay, beach, and supratidal flat complex, similar to the one described above.

Facies relationships within these cycles are interesting, but more important is their limited geologic extent. The uppermost cycle, for instance, is represented over not more than 2 miles in cross section. Attempts at correlating such local cycles without adequate control is unwise. Lithologic variation in these cycles further emphasizes the weakness of long-distance correlations in the Glen Rose on the basis of a particular rock type. Consider, for instance, that there are three Corbula beds in the lower Glen Rose in the Paluxy Valley; which (if any) of these beds correlates with the key Corbula bed of the Austin area?

Sand-delta cycle (beds 11 through 14 of fig. 2). -- The next cycle is just above the middle part of the lower Glen Rose. It can be recognized upstream from Lanham by the lower unit, an 8-inch to foot-thick massive, spar-cemented packstone that either forms a prominent ledge or erodes out into massive blocks, reminiscent of very large flagstones. Downstream from Lanham, the basal unit is lumpy rather than flaggy but has prominent U-shaped burrows 4 to 6 inches deep. Overlying this massive flaggy bed is a sequence of gypsiferous mudstones and distinctive, thinly rippled, ostracod-rich sandstones which are commonly cemented by poikiloblastic spar that shows good cleavage faces. The top of the cycle is marked by the appearance of a hackly, reddish-brown miliolid-rich grainstone. Thickness ranges from 2.9 feet downdip at SV-6 to 3.9 feet updip at SV-5; cycle thickness increases updip, not downdip.

The basal flaggy or burrowed bed does not change thickness appreciably, but its fauna and lithology show systematic areal variations. Downdip from SV-3, the lumpy, burrowed biosparites contain common articulated shells, many of which are in living position; living shells decrease updip from SV-3 until most of the bed is composed of sorted and abraded plateform-shell grainstone, cemented by sparry calcite. The top of the bed, from SV-5 upstream, contains dismicrite as well as plate packstone. Downdip and downstream from SV-3, this bed is the product of shallow subtidal deposition; it is progressively replaced by intertidal grainstone changing to supratidal dismicrite updip. The intrastratal sparry calcite cement suggests fresh-water diagenesis rather than hypersaline diagenesis; river channels as far downdip as SV-11 also indicate increasing fresh-water influence.

The upper phase of the cycle is particularly interesting, although interpretation of any vertical profile can be confusing because one sees an apparently random admixture of gypsiferous mudstone, ostracod-bearing, poikiloblastic spar-cemented fine sandstone and clean, friable quartzarenite. However, through

matching of sections it becomes apparent that there are at least three irregularly placed sand wedges in this part of the cycle; most of the sands are bioturbated and rich in ostracods. A key to the origin of these sand wedges is found in the upper 2 feet of the cycle in sections SV-7 to SV-11. At SV-7, the lower 2 feet of the sand-rich phase contains sands and sandy shales with rounded lignite fragments. A convex-downward lens of friable, unfossiliferous medium quartzarenite with an erosional base cuts into this interval and occupies the next foot of section; the sand cannot be traced laterally through the hundred-plus yards of outcrop at SV-7. Cut-and-fill beds in this sand dip southeasterly. Overlying this sand is an ostracod-rich medium quartzarenite which is strongly bioturbated. Between SV-1 and SV-11, the lignitic sandy shales gradually become gypsiferous, with Frenelopsis instead of lignite fragments. Concurrently, the southeastward-dipping unfossiliferous sands begin to interbed with northwestward-dipping, ostracod-bearing sands. Farther downstream, toward SV-11, the base of the sand unit shows less evidence of erosion; instead, the sand bodies assume the form of low mounds apparent in cross section instead of longitudinal section. Load-casts mark the bases of the lenses, ostracods abound in the sands, and low-angle inclined beds are common. Similar low mound-like lenses appear progressively higher in the section in a downdip direction. Still farther downdip, the ostracod-rich sands are strongly bioturbated. Within the shales are thin (up to 3/4 inch thick), short wavelength (3-6 inches) ripples of ostracod-rich, poikiloblastic spar-cemented quartzarenites; orientation and inclination of these ripples indicate that they were laid down by northwesterly currents. The sands in the upper 2 feet of the cycle thin, become more calcareous, and become more strongly bioturbated downdip and away from SV-7 and SV-11. At SV-7 and SV-11, the sands are bioturbated only in the uppermost parts of the zone.

The friable sand at SV-7 possibly represents a channel in a flood plain; water in this channel flowed to the southeast. By SV-11, the flood plain graded into a Frenelopsis marsh, and the channel sands show bimodality of dip, probably because of tidal influence. Downstream from SV-11, the channel breaks up into a channel-mouth bar with low-angle inclined beds and load-casts formed during pile-up of sand. Bioturbated sands beyond and above the bar are apparently destructional phase units; the ostracod-bearing, northwest-dipping, rippled sands represent part of the destructional phase sands that were thrown back over the marsh during storms. Some of these sands show hopper crystal casts, a result of evaporation of the marine storm waters. The channel-mouth bar appears progressively higher in the section downdip because of shoreline progradation. The channel and associated features are relatively small elements in the much larger sand wedge which is predominantly bioturbated; the configuration of the whole is best explained as a lobate sand body, with the fluviatile channel supplying sand for progradational construction of the lobe. The whole upper portion of the feature was eventually veneered with the destructional phase ostracod-bearing quartzarenite.

The other sand wedges are interpreted on the basis of the uppermost wedge; the interpretations are diagrammatically presented in figure 6. Upstream from

SV-4, beds above the flaggy unit have all the characteristics of flood-plain deposits--thinly interlaminated sand and clay with lignite clasts, cut by friable channel sands. In SV-6 through SV-2, the basal, ostracod-rich sand with partially mottle-disrupted laminae represents the destructional phase of a sand lobe such as described above; thickness trends indicate that the source of sand, probably another fluviatile channel, was to the north of the present Paluxy Valley. The intermediate-level rippled sand and clay is thickest to the south, centering around SV-3 and SV-12; it thins and interfingers with marsh shales to the north and east. Ripples in this sand trend northwest; near the top of the bed the ripples are destroyed by bioturbation at SV-12. This sand represents the destructional to supratidal phase of a sand wedge to the south of the present river valley. The uppermost sand wedge and channel center around the present Paluxy Valley, as seen in SV-7 and SV-11.

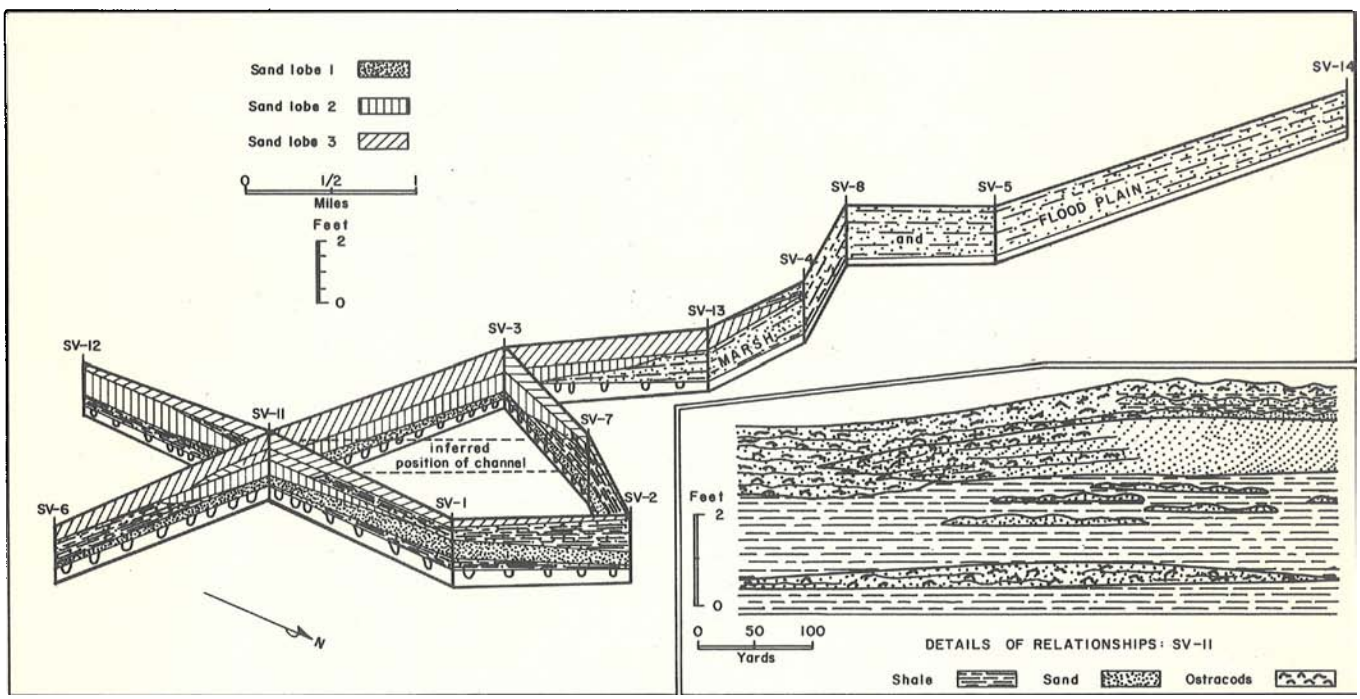

FIG. 6. Reconstruction of facies in sand-delta cycle, so named because of the overlapping sand lenses, each of which is interpreted to represent a lobe of a small, lagoon-margin delta. Each lens is indicated by a different pattern. Basic rock types and structures at one outcrop (SV-11) exemplify the lithologic basis for the interpretation and are detailed in the inset.

The entire subterrestrial phase of this cycle is best explained as a small, sand-rich delta. It possessed at least one relatively small channel that interacted with the sea during the progradational-constructional phase; its sands underwent widespread marine dispersal during the destructional phase. Thickness and directional structure dispersal evidence indicates that the source of sand, probably the channel, shifted at least three times during the construction of the feature, to produce a multi-lobed delta.

The final destructional phase of this cycle is manifested by a thin zone of rippled, reddish-brown, miliolid-rich grainstone which overlies and interfingers with the ostracod-bearing sands. The reddish grainstone biosparites invaded the area from the north, as shown by the orientation and inclination of the ripples, strong contrast to the previous destructional phases, which invaded from the southeast.

Miliolid-sand and mussel-marsh cycles (beds 15 through 19 of fig. 2). -- The uppermost two cycles of the lower Glen Rose are discussed together because they are similar in most aspects; only details of the subtidal phase differ to any extent. Complete exposures are principally found on the south side of the Paluxy, as diagrammed on the cross section (fig. 7). The sixth cycle can be recognized by its basal unit, a miliolid-ostracod packstone that weathers a distinctive reddish brown. Lignitic and sandy shale overlies this biosparite through most of the area, but two subcycles developed within this interval at SV-6 and SV-16 to the southeast. Here, there is a series of irregularly bedded biomicrites and biosparites interzoned with plant-bearing gypsiferous shales. The uppermost cycle is also distinguished by the basal unit, a sandy biosparite containing abundant clumps of marsh mussels, Modiola branneri Hill (1893, p. 24). Its upper phase is nearly identical to that of the sixth cycle. The lowest beds of the Thorp Spring Member overlie these cycles. Both cycles thicken updip, the sixth from 3.4 feet at SV-6 to 6.9 feet at SV-14 and the seventh or uppermost cycle from 2.1 feet at SV-16 to 9.0 feet at SV-14. The basal subtidal phases are never more than 0.8 foot thick; changes in thickness correspond to supratidal clastic wedges entering from the northwest. These cycles contrast strongly with the lowermost cycles, which thicken downdip and which have a relatively thick subtidal phase. The middle cycles show intermediate trends. Lithology and biota of the upper and lower cycles also contrast. There is a general lack of dolomite and an abundance of sparry calcite in the upper cycles, the opposite to the lower cycles. The biota of the upper cycles is rich in Foraminifera and largely detrital, that of the lower cycles is rich in ostracods and is largely in place.

Ripple inclination and thickness trends indicate that the reddish-brown "destructional phase" packstone invaded the area from the north. The completely bioturbated subtidal to intertidal phase of this zone is best developed to the north and east (SV-11), where it is up to 0.6 foot thick and contains 1- to 2-inch deep U-shaped burrows; the bioturbated portion drops out by SV-5. Shells are mostly detrital and well sorted; the water here was always very shallow and well agitated. Above and updip from this bioturbated zone, the biosparite becomes a rippled

miliolid grainstone within a shaly sequence, representing a supratidal phase. The miliolid sands were also transported southward in this phase, as shown by the orientation and inclination of the ripples. The sandy lignitic shales overlying this unit contain a channel complex with dinosaur tracks and load-casted beds, interpreted here as a flood-plain deposit. These beds are well exposed in sections SV-4, SV-5, and SV-14. Frenelopsis, gypsum, and small amounts of detrital shell appear at SV-12; here, the shales represent a marsh. Farther east, at SV-6 and SV-16, two new cycles appear within the shales. They show a vertical succession of biomicrite at the base, through biosparites to fine, plant-bearing shales; a characteristic subtidal through supratidal marsh succession. The calcareous phase rapidly replaces the shaly marsh downdip, until there are only a few inches of marsh at SV-16.

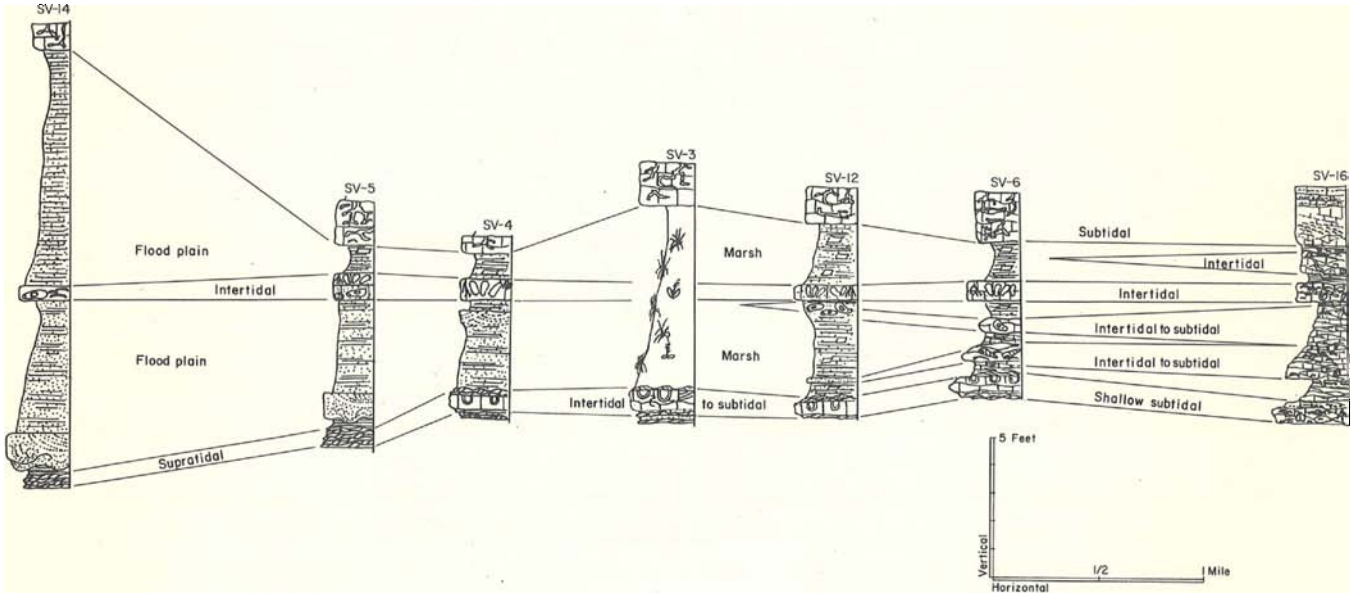

FIG. 7. Facies interpretations, miliolid-sand and marsh-mussel cycles. These cycles show only downdip variations, hence are presented in cross section. Subtidal deposits of the miliolid-sand cycle contain innumerable miliolid tests; the subtidal and intertidal deposits of the marsh-mussel cycle characteristically contain clumps of Modiola, a marsh mussel.

The uppermost cycle of the lower Glen Rose resembles the cycle below it in that it is marked by a thin and widespread shelly unit overlain by a flood plain and marsh to the northwest and by an intermediate subcycle to the southeast. The lowermost few inches of the basal unit contain oysters (Crassostrea camelina (Cragin, 1893, p. 129)) and bored cobbles at some places but is always overlain by a root-bearing sandy biomicrite with clumps of mussels (Modiola branneri). The oyster-bearing zone continues updip and is present at the town of Paluxy (HO-1); it represents the lowered salinity (Parker, 1960, p. 310)

transgressional phase of the cycle. The root-bearing biomicrite with marsh mussels, similar to present-day mussels which occur in rooted marsh sediments, probably represents an intertidal progradational marsh phase. A clastic wedge of flood-plain deposits occupies the upper unit to the northwest; it is replaced by Frenelopsis marsh to the southeast. Finally, a subcycle divides the marsh at SV-16. The basal subtidal unit of the Thorp Spring Member overlies this cycle; it extends a great distance updip and is marked by a diverse, normal marine fauna representing a far greater transgression than is seen in the lower Glen Rose.

These two cycles, with their intervening subcycles to the southeast, reiterate the local nature of the Glen Rose cycle and the tendency for proliferation of cycles downdip. They also demonstrate that the cycle can be recognized only where it is reasonably well developed; if the marine phase is absent, for practical purposes so is the cycle.

SUMMARY AND CONCLUSIONS

(1) Cyclical alternation of subtidal through supratidal deposits is responsible for the alternating beds of the Glen Rose. Cycles are everywhere regressional, resulting from the progradation of shorelines over subtidal facies; the pattern indicates a subtidal to supratidal depositional régimé transit. The supratidal phase commonly comprises more than half of a Glen Rose cycle; hence much of the Glen Rose in this area was deposited above mean sea level.

(2) The variety of facies within cycles, plus the mixture of terrestrial, marginal marine, and marine floras and faunas within these facies tracts, indicate that the lower Glen Rose in this area is the product of a lagoonal or bay depositional system. Beds within a cycle commonly remain approximately constant in thickness, but drastic facies changes within some beds take place in a matter of miles.

(3) Correlation of cycles is not feasible because of their areal restriction, downdip proliferation, and recurrence of potential key beds in homotaxial portions of the cycle.

(4) Cycles not influenced by clastic flood-plain wedges thicken downdip; cycles with such wedges thicken updip.

(5) Local facies patterns are superposed on the general cycle; from this it is possible to reconstruct the history of an area. The lower Glen Rose in the Paluxy Valley is comprised of seven major cycles, representing a succession from hypersaline bays through marsh islands, a sand delta, and subterrestrial plains. Salinity progressively decreased upwards from hypersaline to normal

marine, probably because of a progressively increasing influx of fresh water accompanying increasing development of fluviatile phases. Diagenetic régimés follow this trend, from hypersaline stratal dolomitization below to fresh-water sparry calcite cementation above.

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